AN INVESTIGATION OF TRANSITIONAL MANAGAMENT PROBLEMS FOR THE NSTS

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ANNUAL REPORT

BY JOHN L. HUNSUCKER

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CHAPTER 1

INTRODUCTION

During the period from April 1, 1990 to May 31, 1991, a research team from the Department of Industrial Engineering at the University of Houston worked on a research grant from the Shuttle Program Office at Johnson Space Center. The intent of this research was two-fold. One purpose was to find ways and means of helping the Shuttle Program become more operational in nature. The other purpose was to develop the theory of flow shop scheduling with multiple processors. Flow shop scheduling with multiple processors is, in essence, the environment that the Shuttle is scheduled under at Kennedy Space Center. Some of the jobs at JSC also fall under this type of scheduling regime. The research team has in essence been working on these problems since the summer of 1984 when the principal investigator was employed by NASA to work on these issues. This report is the result of the current year's work and the culmination of the ongoing effort since 1984. The intent of the report is primarily to show the results of the research in both the scheduling and the management of operations areas. A secondary purpose of the report is to illustrate the impact and scope that both the support of the research and the research itself have had on the scientific and academic community.

The rest of the report is divided into two major sections and an appendix. Chapter 2 deals with the management of change and operational issues. Chapter 3 covers the results on scheduling. Appendix A covers the contribution to higher education made possible by the grant while Appendix B lists publications and presentations made possible by the grant.

CHAPTER 2

TRANSITION MANAGEMENT AND MOVEMENT TO OPERATIONS

INTRODUCTION

The information, findings, and opinions in this report are based on both the past years and on the current year's work. In particular there are four sources of information: interviews with top managers of companies which have undergone a change similar to the move towards operations intended for the Shuttle, a questionnaire sent to top-level managers of 250 high tech Fortune 500 companies, the literature on the management of change and the management of operations extant today, and the day-to-day interaction of the Principal Investigator with the Program Office of the Shuttle.

In the discussion that follows, these sources will be cited on several occasions. The interview process [4,5] consisted of meeting with managers of high-tech companies which had undergone a significant transition in the immediate past. More than two dozen companies were interviewed. The interview itself consisted of a rather open ended discussion of the transition and tended to concentrate on strategies used to manage the transition, problems and issues that arose with the transition, and methods used to deal with these problems.

From these interviews, a survey [7] was developed that was sent to Fortune 500 companies that were high-tech in nature and that had undergone a recent significant change.

BACKGROUND

For the purpose of this report, the terms operations and operational are used somewhat differently than is common in the aerospace industry. These terms will be reserved to refer to a state that is not only safety and performance driven but also cost and schedule driven. In an operational state, safety, performance, cost, and schedule are controllable and stable.

The Shuttle is not now, by this definition, in an operational state. Cost and schedule do not receive near the attention that safety and performance do. In addition, the environment does not appear to be either controllable or stable to the degree required by an operational program.

Many different factors may well require the Program to obtain higher levels of performance from the Shuttle. These factors include the Space Station and the President's National Space Policy. Higher levels of performance may well only be possible with an increased flight rate. This in turn will require a shorter turn around time at KSC and a more expedient mission planning and design time at JSC. The amount of time available for training may well have to decrease. In addition, different types of missions may well be required of the Shuttle in order to support these efforts. All of this may be necessary without a commensurate increase in the Shuttle budget. In other words, the Shuttle may be required to do more with essentially the same amount of resource.

The rank and file technical managers at NASA are now as good as they ever were. In fact there is a large cross section of these engineers and scientists who have been at NASA from its beginning or very nearly so. True, they may be older but one hopes they are also wiser. These managers are among the best technical managers in the world. As a specific example, quality has never been an issue at NASA. For that matter, neither has pride. Anyone who was at NASA during the time of the Challenger accident knows that the work force felt this accident on a very personal level. It was a blow to their professional ego as well as a loss of friends and colleagues. So in the rank and file worker, we have individuals who take pride in turning out high quality work and have consistently done so over the last several decades.

BARRIERS TO OPERATIONS

The following issues are felt to be among those that will be major barriers to attaining a stable production flow which will result in a predictable and steady flight rate.

PURPOSE AND OBJECTIVE - At best the objective of the Shuttle program could be defined as very fuzzy. There seems to be little understanding of or commitment to the purpose. In order to illustrate this point, how is success measured? If one does not know what the objective is then one cannot tell if they have been successful. There seems to be little consensus of opinion on exactly what is the purpose of the Shuttle. Earlier space programs at least gave the impression that everyone on the team was striving for the same set of goals.

LACK OF NATIONAL INITIATIVE AND SUPPORT - If NASA does not know what it is doing with the Shuttle, the American people clearly do not. A major barrier to operations will be the convincing of the people, along with their Congress, that the purpose of the Program is well defined and the Program is on its way to achieving that purpose. Until this happens, problems such as uncertain budgets will continue to occur.

LACK OF PRESSURE - At the present, there seems to be little if any pressure on the Shuttle to perform. There is no exceptionally large backlog of flights waiting to happen. If there is a pressure it does not seem to get transmitted into the operations.

Perhaps the issue here is that if you are unsure of what you are doing, then there is no need to do it in a hurry.

DESIGN CHANGES - There are a large amount of changes still occurring in the basic processing system as well as in the orbiter. Many of these may well be referred to as tweaking the system. In blunt terms, to become operational it will be necessary to make the decision of when good is good enough, and when safe is safe enough. It will be necessary to quit making the changes that will fly you a little higher or faster, or let you carry a little more, and concentrate only on the changes that will let you fly more frequently. In the parlance of operations management, it is time to "shoot the engineer".

LACK OF UNDERSTANDING OF OPERATIONAL CONCEPTS - NASA has had very few programs which were truly operational in nature. Much of what has gone before had a definite lifetime. The lifetime of the Shuttle is, in essence, infinite. That is to say, not that the Shuttle will continue forever but rather that it will be managed as if there is no foreseeable end to Shuttle flights. Many of the concepts and skills required to work a program through its operational era are foreign to NASA management. As a specific example, much of what is done on Shuttle flights is still more project oriented than process oriented. A large amount of standardization and stabilization must occur before routine space flight of the Shuttle will become a reality. The processing of the Orbiter provides another example. There are numerous places where the Orbiter is not in a "value adding mode".

FACILITY LAYOUT - Many of the processing facilities at the Cape were designed when schedule was not critical. Long flow lines, with large and awkward transports of equipment, reduce the ability of the system to shorten the process flow time. This "non-value added time" will hamper any attempt to fly frequently.

AGEING EQUIPMENT - The Orbiters are getting older. The equipment, in many cases, is no longer state of the art. Older equipment tends to wear out faster and require more maintenance. With age, the probability of failure due to equipment fatigue goes up.

THE WRONG PEOPLE - Much of what makes a manager successful is intuitive and learned on the job. The people at NASA have for the most part only worked at NASA for the bulk of their career. What they know, and know very well, is how to get something up in space. What they neither know nor understand is how to do this with the same piece of equipment, flight after flight, over a long period of time. While there is no better group to design a transition to an operational era there is also probably no worse group that can attempt to manage an operational era.

LEADERSHIP AND STRUCTURE - Many of these barriers are leadership issues and consequently begin with the President of the United States, extend through the Congress to the Administrator of NASA, and down to the Program Managers. What perhaps is missing is vision, the ability to look ahead. Instead of focusing entirely on the next flight, some consideration needs to be given to the next decade. Planning and aggressive leadership with vision could move the Shuttle to an operational era within a few years time.

LACK OF UNDERSTANDING OF THE RESEARCH REQUIRED - Trying to make the Shuttle Program operational is a task of significant magnitude, at least the equivalent of the invasion of Normandy in World War II. This invasion is sometimes given credit as leading to the formulation of the field of Operations Research. Issues such as the fatigue induced on reflight hardware, time and motion studies for space manufacturing, effects of long space duration on physical and mental characteristics are just part of a long list of items that need serious attention. It is not clear that there is an awareness of the magnitude of the amount of research involved.

THE WAY OUT

There are two essential moves to find the way to an operational era. One is cross training and the other is to build an operational arm for the management of the Shuttle. An aggressive cross training program in operational concepts would help to build the skill level necessary to manage operations. Separating the management of the Shuttle from other NASA programs would allow for a fertile field for these skills to mature. This would also allow the rest of NASA to get back to what they have always done so well, research and development.

PREDICTIONS

NASA has the tendency, when faced with a problem, to commission some group to study the problem. Then, as a rule, they tend to ignore the study until the problem resurfaces. At this point the strategy is usually to appoint another commission to study the problem again. All of this is rather like a little old lady who dithers from advisor to advisor before finally taking action, generally much too late for it to be effective. As a case in point, the issue of whether NASA should concentrate on a Space Station, a colony on the moon, or on a flight to Mars as an example. The truth is, of course, that all of these will eventually be done. Correspondingly, it does not matter so much which is done as it matters that whichever is done, it is done very well. With the Shuttle, it is time to make some hard decisions, quit dithering, and get on with the program.

The probability that NASA can break out of its current mode of management is very slim. Consequently, the highest probability seems to be that the program will continue in a mode much as it is in at the present until it whimpers to a conclusion. The great loss here is that the agency could be using the Shuttle to learn about space operations. It could be a tremendous test bed for space operations concepts. Unfortunately this requires vision.

CHAPTER 3 - SCHEDULING RESULTS

Introduction

A schedule is a timetable for performing activities, utilizing resources, or allocating facilities. The purpose of production scheduling is to determine a schedule which will optimize predetermined criteria. Thus, the production scheduling problem mainly involves determining the order in which the jobs must be processed on each machine in the production system to optimize a predetermined scheduling criterion (or set of criteria).

A scheduling criterion is the measure upon which the schedules are compared and evaluated. Scheduling criteria are classified into two categories depending upon whether they use schedule cost or performance to evaluate the schedule generated. The scheduling cost associated with a schedule is the sum of the following costs: capital costs associated with production setups or changeover, variable production and overtime costs, inventory holding costs, shortage costs, and cost associated with the lateness penalty. The schedule performance measures commonly used to evaluate schedules include the mean flow time for the set of jobs considered, makespan, number of tardy jobs, mean tardiness of jobs, and mean utilization of the production resources. The reader may refer to French [3] for the definitions of the above listed performance measures. A list of some of the optimizing criteria often used in scheduling research is provided in Table 1.

Production scheduling problem may be classified into a particular category on the basis of the number of processing steps required to complete the jobs. According to this dimension a production scheduling problem may be classified as a single machine, parallel machine, flow shop, or a job shop problem. For a detailed definition of these problems the reader is again referred to French [3].

The purpose of this chapter is to discuss the research performed in the area of scheduling with the support of this grant. One of the major purpose of performing research in scheduling was to explore the theoretic basis behind the ways and means that could be used to increase the flight rate of the Shuttle. This task was accomplished by analyzing the processing requirements of the Shuttle. This analysis revealed that the Space Shuttle Scheduling problem cannot be classified into the previously mentioned categories of the scheduling problems. We have developed a new category based upon its processing environment. It is known as the 'Flow Shop with Multiple Processors Environment' which is defined below.

TABLE 1. Criteria of Optimality

CRITERIA BASED ON COMPLETION TIME
Maximum Completion Time
Maximum Flow Time
Total Completion Time
Total Flow Time
Mean Completion Time
Mean Flow Time
Weighted Sum of Completion Time
Weighted Sum of Flow Time
Job's Waiting Time
Weighted Job Waiting Time
CRITERIA BASED ON DUE DATES
Maximum Lateness
Maximum Tardiness
Maximum Earliness
Total Lateness
Total Tardiness
Total Earliness
Mean Tardiness
Mean Earliness
Weighted Sum of Lateness
Weighted Sum of Tardiness
Weighted Sum of Earliness
Number of Tardy Jobs
Number of Early Jobs
CRITERIA BASED ON INVENTORY COST AND UTILIZATION
Number of Jobs in System
Machine Idle Time
Machine Weighted Idle Time
Man-power Idle Time
Man-Power Weighted Idle Time
Utilization or Mean Utilization
Set-up Time

Flow Shop with Multiple Processors Problem

A flow shop sequencing problem is characterized as the processing of **n** jobs on **m** machines. The machines are laid out in a unidirectional flow pattern and all jobs are assumed to be processed on all of the machines with an identical processing sequence. The flow shop with multiple processors (FSMP) sequencing problem involves sequencing of **n** jobs in a flow shop, where more than one identical machine at a stage is allowable. Further, a FSMP sequencing problem subjected to any constraint may be defined as a constrained flow shop with multiple processors (CFSMP) problem.

Detailed analysis of the Space Shuttle scheduling problem revealed that it can be correctly represented as a CFSMP problem. The CFSMP problem addressed by the research team is a FSMP problem subjected to a constraint which limits the total number of jobs that can exist concurrently in the system (i.e., jobs in the queue + jobs being processed) without any explicit limitation on the number of jobs that can exist concurrently at a particular buffer. Results obtained for this CFSMP sequencing problem can be directly applied to the processing of Space Shuttles at the Kennedy Space Center (KSC). As shown in Figure 1, a mission in space, corresponding to a job in the manufacturing shop, is processed by taking a Space Shuttle through the Orbiter Processing Facility (OPF), Vertical Assembly Building (VAB),

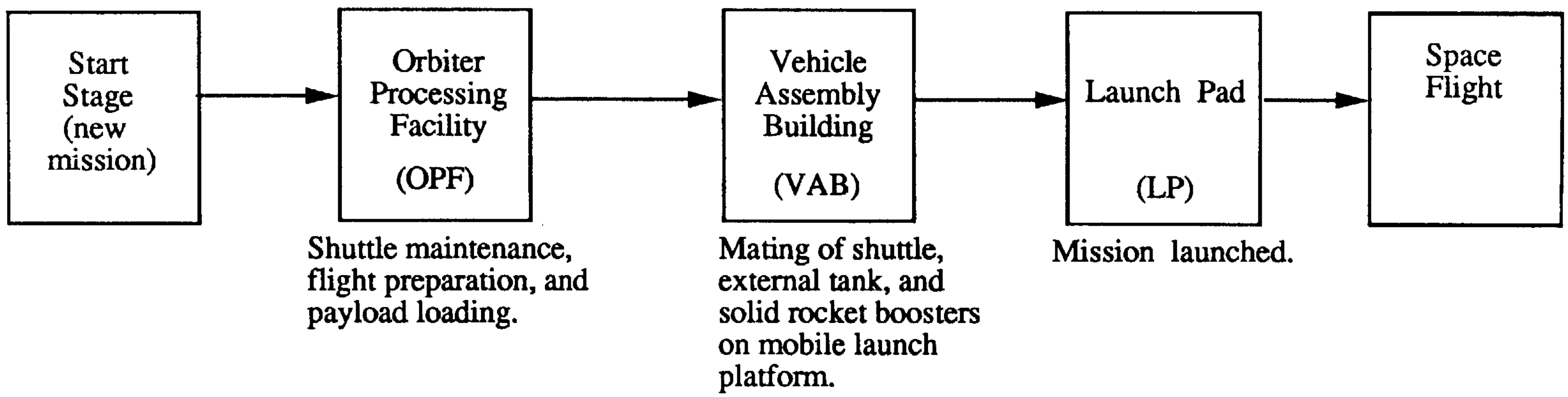


Figure 1. Schematic representation of the space shuttle processing flow.

and Launch Pad (LP) in the same processing sequencing. There are multiple processing facilities at each processing stage and the shuttle can be processed on any one of them. However, the number of Space Shuttles that can concurrently exist in the system is limited because the number of Shuttles is limited as is the number of transporters which are used to carry the Space Shuttle through the system. Figures 2 and 3 are the schematic representation of the FSMP and CFSMP problems respectively.

The FSMP and CFSMP scheduling environments are significant to the National Space and Transportation System (NSTS) because the Space Shuttle orbiter processing problem can be modeled as one of the above problems. Most of the research performed in this grant has been concentrated on the development of analytical methods to solve the problems in these categories or to simulation studies which have been performed to understand in detail the structure of the problems. Thus, the remainder of this discussion is divided into the following subsections: 1. Research related to optimal solution methodologies, and 2. Heuristic programming studies.

Optimal Solution Methodologies

Because of the inherent complexity of most real life scheduling problems, algorithms to optimally solve the

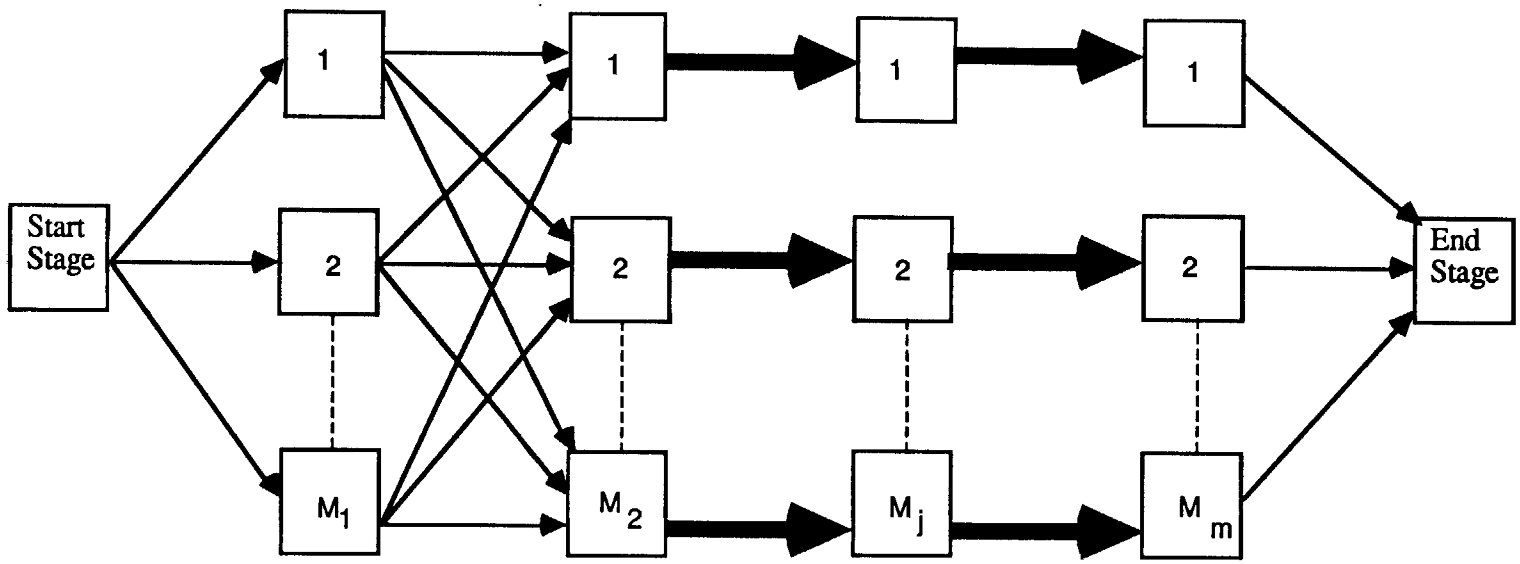
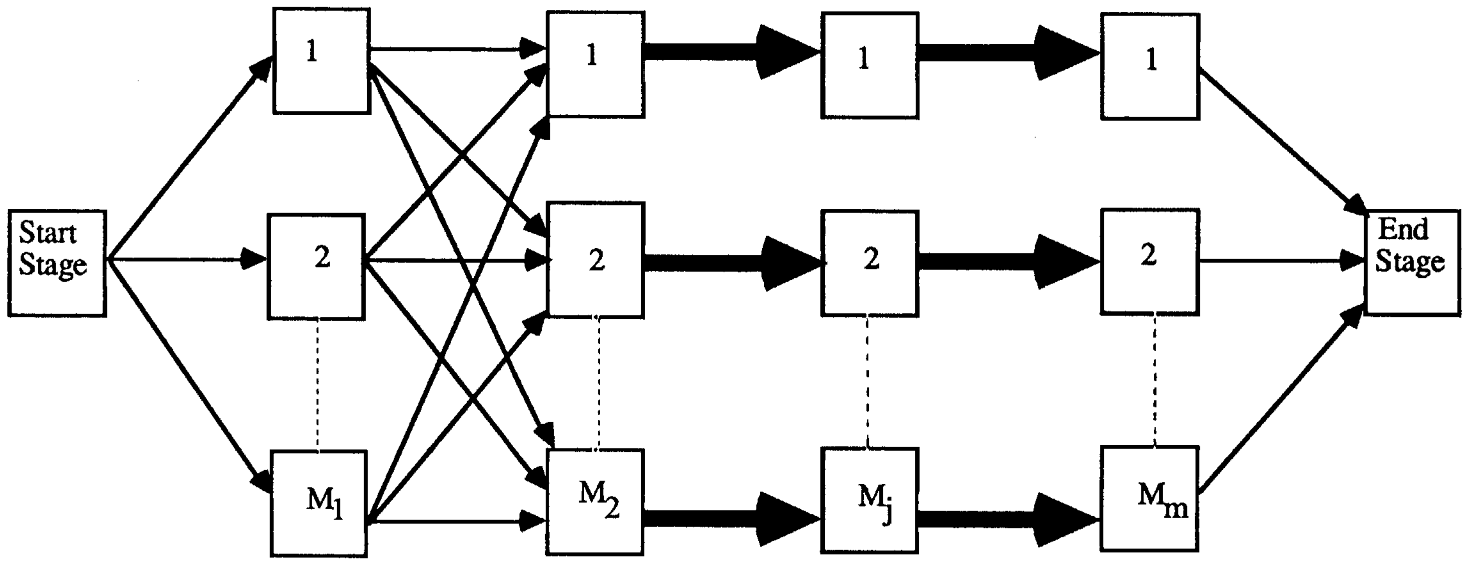


Figure 2.. Schematic representation of a flow shop with multiple processors.



Constraint - $[(n_1 + p_1) + (n_2 + p_2) + ... + (n_j + p_j) + ... + (n_m + p_m)] \leq CN$

Figure 3. Schematic representation of the CFSMP scheduling problem.

problems in polynomial time have been almost nonexistent. Non-polynomial time algorithms are those algorithms where, if the problem size increases linearly, the algorithm may grow exponentially in time. In other words, if the problem size increased by a small amount, then the time to solve the problem would grow unproportionally larger. Problems which cannot be solved in polynomial time are termed as NP-complete. Research done in support of the grant has shown that the FSMP is an NP-complete problem. Therefore, in the absence of polynomial time algorithms, general purpose optimization methodologies such as mathematical programming and the branch and bound method have been historically used in an attempt to optimize the predetermined criteria. Efforts of this grant have produced both a mixed integer mathematical programming (MIP) model and a branch and bound algorithm for the flow shop with multiple processors.

Mathematical Programming Model for the FSMP

The mixed integer program model of the flow shop with multiple processors is presented in Table 2 at the end of this section [1]. The formulation allows the optimization (minimization) of four different criteria: 1a) Maximum Completion Time, a.k.a. Makespan, 1b) Mean Flow Time, 1c) Maximum Lateness, and 1d) Mean Lateness. Depending on which of the four--1a through 1d--for which optimization is desired, eliminating the other three from the model yields the desired formulation. It should be noted that other

Table 2. MIP for FSMP

Objective Function: Minimize Z

Subject to:

$Z \geq F_{im}$	for all i,	(1a)
or $Z \geq S_i\ F_{im}/n$		(1b)
or $Z \geq F_{im} - d_i$	for all i,	(1c)
or $Z \geq S_i\ (F_{im} - d_i)/n$		(1d)
$S_k\ Y_{ijk} = 1$	for all i, j,	(2)
$F_{ij} - F_{i,j-1} \geq S_k\ Y_{ijk}\ P_{ijk} + t_{ij}$	for all i, j,	(3)
$Q(2-Y_{ijk}-Y_{rjk}+X_{irj})+F_{ij}-F_{rj} \geq P_{ijk}$	for all i,r,j,k such that i < r	(4)
$Q(3-Y_{ijk}-Y_{rjk}-X_{irj})+F_{rj}-F_{ij} \geq P_{rjk}$		

$Y_{ijk} = 0,1$ for all i, j, k,
$X_{irj} = 0,1$ for all i, r, j,
$F_{ij} \geq 0$ for all i, j,

where

n = total number of jobs,
m = total number of machine stages in the flow shop,
i = job index; $i = [1,n]$,
j = machine stage index; $j = [1,m]$,
M_j = total number of parallel machines at stage j,
k = index of machine at stage j; $k = [1,M_j]$,
P_{ijk} = processing time for job i at stage j on machine k,
t_{ij} = travel time of job i from stage j-1 to j,
F_{ij} = flow time of job i at stage j,
Q = a large number $\geq S_i S_j S_k P_{ijk}$,

X_{irj} = 1 if job i precedes job r on stage j at machine k, 0 otherwise,

Y_{ijk} = 1 if job i on stage j is assigned to machine k, 0 otherwise.

criteria can be optimized with the use of this model with minor modifications to equations 1a through 1d.

Branch and Bound Technique for FSMP

Branching and bounding (B&B) is an enumeration technique which attempts to explore the decision tree--consisting of all schedules--in an intelligent fashion. Branching and bounding consists of the following three basic steps: calculation of lower bounds, branching, and node elimination. Branch and bound methods in flow shop scheduling have been widely used in the literature for finding optimal or near optimal solutions. However, one of the significant results of this research has been the creation of a branch and bound technique for the flow shop with multiple processors scheduling problem [2]. It should be noted that the lower bounds developed in this research are generalizations of those used in the pure flow shop environment. For a thorough discussion of the branch and bound technique, the reader of this report is referred to the *European Journal of Operational Research* paper "Branch and bound algorithm for a flow shop with multiple processors scheduling" by Brah and Hunsucker [2].

The two methods presented above--mathematical modeling and B&B--find optimal or near optimal solutions. However, they require extensive computations in order to find the optimum solution for large scale problems. Therefore, other research efforts have focused on finding good solutions through the use of heuristic programming. The subsection below presents a discussion on the heuristic programming studies performed by the research efforts.

Heuristic Programming Studies

Three important heuristic programming studies were performed as a result of the research efforts. These studies are as follows:

1. Simulation study of a static FSMP.
2. Heuristic programming study of CFSMP.
3. Study of changing distributions and ranges in a single stage multiprocessor environment.

Important details and results of the above studies are presented in the following discussion.

Simulation Study of a Static FSMP

A study of a static problem is one in which all jobs are available for scheduling at time zero. This particular study focused on the makespan and mean flow time criteria. In the study, nine priority rules were analyzed under various FSMP configurations. The nine priority rules were as follows:

1. FIFO--first in first out,
2. LIFO--last in first out,
3. SPT--shortest processing time first,
4. LPT--largest processing time first,
5. MTWF--most total work first,

6. LTWF--least total work first,
7. MWRF--most work remaining first,
8. LWRF--least work remaining first and
9. RANDOM--choose next job randomly.

The shop configurations varied according to number of jobs, number of stages, and number of machines at each stage. The number of processors per stage was kept constant throughout all stages. See "An evaluation of dispatching rules in a flow shop with multiple processors" by Hunsucker, Brah, and Santos for a more thorough discussion of the experiment design [4]. Results show that for the mean flow time criterion, SPT, LTWF and LWRF were the three best performers. Of these three, SPT dominates in most shop configurations. For the makespan criterion, SPT, MTWF and MWRF were the three best performers. However, neither of these three show a pattern of dominance over the others for the makespan criterion.

Heuristic Programming Study of CFSMP

A CFSMP is a constrained FSMP. In the CFSMP problem studied in this research effort, the total number of jobs that can concurrently exist in the system is limited to a pre-specified number. Space Shuttle processing is a prime example of a CFSMP due to the limited number of orbiters.

In the study, the following six priority rules were used: FIFO, LIFO, SPT, LPT, MWRF, and LWRF. The study was dynamic in the sense that jobs arrived and left the system throughout the course of time instead of all arriving at time zero. Furthermore, the study analyzed the effects of different congestion levels of jobs in the system. Two different experiments were performed under this study--due-date based scheduling and completion time based scheduling.

Due-Date Based Scheduling

See "An analysis of priority rules in a due date based constrained flow shop with multiple processors environment" by Hunsucker and Shah for a more thorough discussion of the experiment design [5]. In this portion of the experiment, the two criteria under study were mean tardiness and number of tardy jobs. The results of the study provided conclusive evidence of the superiority of FIFO for the mean tardiness criterion. However, clear superiority was not established for the number of tardy jobs criterion. However, it is shown for the number of tardy jobs criterion that general guidelines have been developed for choosing a particular priority rule depending upon the system parameters. Again, the reader is referred to the aforementioned paper for more elaborate details.

Completion Time Based Scheduling

This portion of the study focused on the following three measures of performance: makespan, mean flow time and maximum flow time. The reader is now referred to "Comparative performance analysis of priority rules in a constrained flow shop with multiple processors environment" by Hunsucker and Shah for details on experiment design [6]. Results showed that SPT yielded superior performance for the makespan and mean flow time criteria. However, there was no clear superiority of priority rules for the maximum flow time criteria.

Study of Changing Distributions and Ranges in a Single Stage Multiprocessor Environment

Because simulation studies are only as good as the parameters chosen for use in the study. This study was undertaken in an effort to see if changing the distribution and/or range from which job processing times were obtained would affect the results of a simulation of different heuristic rules. In other words, the study wanted to answer the question "Is the performance of a heuristic dependent upon the parameters chosen for the study?" The study analyzed four different heuristics in the single stage multiprocessor environment. Four different distributions were used and five different ranges were used in the simulation experiment. The reader is referred to "A study on changing distributions and ranges in parallel processor scheduling problems" by Hunsucker and Santos for a thorough description of the experiment design [7]. Results show that by changing distribution and/or range in the simulation study only minor differences are reported on the behavior of the different heuristics.

In addition to the above three heuristic programming studies which have been performed, two additional programming studies are in progress. These are as follows:

1. The effects of adding an additional processor to a FSMP.
2. Due date assignment methods and dispatching rules in a FSMP.

The first study listed above is intended to answer the following question "Given the resources to add an additional processor, at what stage should the processor be placed?" The second study aims to investigate the impact of due date assignment methods on different performance measures in a FSMP. Partial results of these studies were presented at the 16th annual AIAA Technical Symposium, Houston Section in May 1991.

Summary

A significant amount of scheduling research has been developed by the research team in support of the NSTS. The environment studied in this research has been the flow shop with multiple processors and modifications to this environment. The flow shop with multiple processors environment was chosen because the processing of the Space Shuttle orbiter resembles that of an FSMP. The primary concentration has been on two areas: optimal solution methodologies of solving scheduling problems and heuristic programming analyses of scheduling problems.

Two optimal solution methodologies which can be applied to the FSMP were developed as a direct result of this grant. These two applications are the mathematical programming formulation of the FSMP problem and a branch and bound technique for the problem. These methods are designed to produce optimal or near-optimal solutions to the FSMP problem. Because the exact solution methodologies are computationally explosive, meaning as the problem size grows the time required for obtaining solution grows unproportionally larger, the applications are currently limited. However, further adaptation of a programming code for solving the FSMP may be developed to increase the speed of computation thus encouraging the exact solution of FSMP problems using the mathematical model and branch and bound techniques.

Until such modifications, the use of heuristics to find good solutions to larger problems seems necessary. As result of this conclusion, heuristic programming studies have been performed to analyze the FSMP environment. Table 3, attached to the end of this report, provides a guideline for selecting a heuristic given the optimality criteria under study.

Two additional heuristic programming studies are in progress: the effects of adding an additional processor to a FSMP environment and due date assignment methods and dispatching rules in a FSMP.

Table 3. Guideline for Heuristic Selection

Environment	Heuristic
FSMP Static Makespan	SPT, MTWF and MWRF Of these three, no clear dominator.
FSMP Static Mean Flow Time	SPT, LTWF and LWRF SPT dominates in most shop configurations.
CFSMP Dynamic Mean Tardiness	FIFO
CFSMP Dynamic Number of Tardy Jobs	Clear superiority isn't established, see [4] for more information.
CFSMP Dynamic Makespan	SPT
CFSMP Dynamic Mean Flow Time	SPT
CFSMP Dynamic Maximum Flow Time	Clear superiority isn't established, see [4] for more information.

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APPENDIX A

CONTRIBUTION TO HIGHER EDUCATION

INTRODUCTION

During the six years that this research grant has been in place it has supported numerous graduate students. The intention of this appendix is to outline that support along with the work generated by the students.

DIRECT SUPPORT

The grant provided for sixteen man-years of graduate student support. For the first two years the grant supported 2 students each year. For the last four years, the grant supported 3 students each year. These students would have, for the most part, been unable to attend graduate school without support.

The students directly supported by the grant earned three master's degrees and one doctorate. In addition, two more masters will finish and two more doctorates should finish during the next year.

The research work of these students was in one of two fields. One field was Engineering Management or more precisely the management of change in a technical organization. The other was in scheduling. The work in scheduling was predicated by considerations arising from scheduling the orbiter through its processing.

INDIRECT SUPPORT

Due to the proximity of the Principal Investigator to the shuttle program numerous students received indirect support from the grant. For the most part this indirect support involved providing them with research problems from the shuttle environment and monitoring their work on these problems.

This work has resulted in 5 masters degrees with one still in progress. In addition one doctoral student should finish within the next one and one-half years.

One of the major contributions of the work in the educational environment is that it has served as the source of numerous examples in engineering classes at the University. This has been particularly valuable in the Engineering Management graduate program where many of the students come from the aerospace community.

APPENDIX B

LIST OF PAPERS DEVELOPED IN SUPPORT OF THE RESEARCH GRANT

During the five year period of the research grant, work has been done mainly in two subject areas namely, Scheduling and Transition and Strategic Management. Research papers developed during the course of this grant have been grouped under these two subject areas. Further, the papers are subdivided into three categories based upon their status. These categories are:

Category 1 - Papers already published or accepted for publication in a refereed journal,

Category 2 - Papers which are currently being reviewed by the referees of a journal, and

Category 3 - Papers which are currently being developed for publication.

All the papers developed through the research done for this grant are listed below. They are classified on the basis of the above mentioned classification scheme.

SCHEDULING

Category 1

1. "An analysis of priority rules in a constrained flow shop with multiple processors environment," Hunsucker, J.L. and Shah, J.R. Accepted for publication in 'OMEGA - The International Journal of Management Science.'

2. "Branch and bound algorithm for a flow shop with multiple processors scheduling," Hunsucker, J.L. and Brah, S.B. Published in the 'European Journal of Operational Research,' vol. 51 (1991), pp. 88-99.

3. "Mathematical modeling of scheduling problems," Hunsucker, J.L., Brah, S.B. and Shah, J.R. Published in the 'Journal of Information and Optimization Sciences,' vol. 12, 1, (1991), pp. 113-137.

Category 2

1. "Comparative performance analysis of priority rules in a constrained flow shop with multiple processors environment," Hunsucker, J.L. and Shah, J.R. Submitted for review to the 'European Journal of Operational Research.'

Category 3

1. "A study on changing distributions and ranges in parallel processor scheduling problems," Hunsucker, J.L. and Santos, D.L. Submitted for review to 'OMEGA - The International Journal of Management Science.'

2. "An evaluation of dispatching rules for a flow shop with multiple processors," Hunsucker, J.L., Brah, S.B. and Santos, D.L.

3. "Due date assignment methods and dispatching rules in a flow shop with multiple processors," Hunsucker, J.L. and Martinez, J.

4. "Effects of adding additional machine to flow shop with multiple processors," Hunsucker, J.L. and Santos, D.L.

TRANSITION AND STRATEGIC MANAGEMENT

Category 1

1. "How NASA moved from R&D to operations," Hunsucker, J.L., Brah, S.B. and Santos, D.L. Selected as one of the best papers of the year, 1989, and was reprinted in the 'IEEE Engineering Management Review,' vol. 18, 4, 1990.

2. "Concepts from industrial transitions," Hunsucker, J.L. and Martinez, J. Published in 'Industrial Management' Journal, vol. 33, 3, May/June 1991.

3. "How NASA moved from R&D to operations," Hunsucker, J.L., Brah, S.B. and Santos, D.L. Published in the 'Long Range Planning,' vol. 22, 6, 1989.

4. "Transition management: An analysis of strategic considerations for effective implementation," Hunsucker, J.L. and Loos, D. Published in the 'Engineering Management International,' vol. 5, 1989.

5. "Mobility of engineers in the job market: Frequency and reasons," Hunsucker, J.L. and Ossario, L. Published in the 'International Journal of Manpower,' vol. 10, 3, 1989.

6. "Transition management - A structured perspective," Hunsucker, J.L., Law, J.S. and Sitton, R.W. Published in the 'IEEE Transactions on Engineering Management,' vol. 35, 3, 1988.

7. "An analysis of the flight rate capability of NASA's space shuttle program," Hunsucker, J.L. and Brah, S.B. Published in the 'Logistics Spectrum, Journal of the

Society of Logistics Engineers,' vol. 21, 3, 1987.

8. "Disaster on flight 51-L: An IE perspective on the challenger accident," Hunsucker, J.L. and Law, J.S. Published in 'Industrial Management,' vol. 28, 5, 1986.

Category 2

1. "Strategic considerations for planning major transitions," Hunsucker, J.L., Shah, J.R. and Santos, D.L. Submitted for review to the 'Engineering Management Journal.'

2. "A survey of engineering management practices in transition management," Hunsucker, J.L. and Sitton, R.W. Submitted for review to the 'Journal of Management Studies.'

3. "An operational arm for the management of the space shuttle," Hunsucker, J.L., Brah, S.B., Sitton, R.W. and Santos, D.L. Submitted for review to the 'Leadership and Organization Development Journal.'

4. "Key issues for planning and implementing organization transitions," Hunsucker, J.L. Submitted for review to the 'IEEE Transactions on Engineering Management.'

5. "The effects of a work systems change in a technical organization: A case study,' Hunsucker, J.L. and Waldheim, R. Submitted for review to the 'IEEE Transactions on Engineering Management.'

6. "A look at technical employees for organization known for its engineering," Hunsucker, J.L. and Shah, J.R. Submitted for review to the 'Journal of Engineering Education.'

7. "An engineering management viewpoint of industrial transition," Hunsucker, J.L. and Sitton, R.W. Submitted for review to the 'Long Range Planning.'

8. "Creating a transition management program," Hunsucker, J.L., Santos, D.L. and Brah, S.B. Submitted for review to the 'SAM Advanced Management Journal.'

Category 3

1. "A management decision model for discrete maintenance," Hunsucker, J.L. and Damak, Dorra.

2. "A study of the interrelationships of transition management techniques during organizational change," Hunsucker, J.L. and Sitton, R.W.

3. "A life cycle model for the management of organizational change: An R&D to operations perspective," Hunsucker, J.L., Brah, S.B., Santos, D.L. and Sitton, R.W.

4. "The emerging manufacturing philosophy," Hunsucker, J.L. and Shah, J.R.

LIST OF PRESENTATIONS SPONSORED IN WHOLE OR PART BY THE RESEARCH GRANT

The list of presentations made during the course of this research grant are categorized into two groups namely, Scheduling and Transition and Strategic Management.

SCHEDULING

1. "The effects of adding an additional machine to a flow shop environment," Hunsucker, J.L. and Santos, D.L. Paper to be presented at the 16th annual AIAA conference, May, 1991, Houston.

2. "Managing by due dates," Hunsucker, J.L. and Martinez, J. Paper to be presented at the 16th annual AIAA conference, May, 1991, Houston.

3. "Heuristic programming study of flow shop with multiple processors," Hunsucker, J.L., Brah, S.B. and Santos, D.L. Paper presented at the TIMS/ORSA joint national meeting, Oct. 16-18, 1989, New York City.

4. "Branch and bound method for flow shop with multiple processors scheduling," Hunsucker, J.L. and Brah, S.B. Paper presented at the TIMS/ORSA joint national meeting, Apr. 25-27, 1988, Washington D.C.

5. "Optimal scheduling in an m-stage flow shop with multiple processors," Hunsucker, J.L. and Brah, S.B. Paper presented at the TIMS/ORSA joint national meeting, May 4-6, 1987, New Orleans.

TRANSITION AND STRATEGIC MANAGEMENT

1. "Practical guidelines for transition management," Hunsucker, J.L. and Shah, J.R. Paper to be presented at the 16th annual AIAA conference, May 1991, Houston, TX.

2. "Key issues for planning and implementing organizational transitions," Hunsucker, J.L. Paper presented at the IEEE International Engineering Management Conference, Oct. 21-24, 1990, Santa Clara, CA.

3. "Strategic considerations for planning major transitions," Hunsucker, J.L., Santos, D.L. and Shah, J.R. Paper presented at the 11th annual ASEM meeting, St. Louis, MO.

4. "Industrial engineering standards for aquatics," Hunsucker, J.L. Paper presented at the conference of the Council of National Co-operation for Aquatics, Oct. 1990, San Diego, CA.

5. "A management viewpoint of TQM," Hunsucker, J.L. Paper presented at the Reliability and Quality Management conference, Oct. 1990, Houston, TX.

6. "Industrial applications of transition management methodologies," Hunsucker, J.L. and Martinez, J. Paper presented at the 15th annual AIAA conference, May 1990, Houston, TX.

7. "Implementing new manufacturing technologies," Hunsucker, J.L. and Santos, D.L. Paper presented at the 14th annual AIAA conference, May 1989, Houston, TX.

8. "What is the new manufacturing philosophy," Hunsucker, J.L. and Shah, J.R. Paper presented at the 14th annual AIAA conference, May 1989, Houston, TX.

9. "An engineering management perspective on transition management," Hunsucker, J.L. and Sitton, R.W. Paper presented at the proceedings of the 9th annual conference of the ASEM, Oct. 1988, Knoxville, TN.

10. "Analysis of alternatives for the management of the space shuttle program," Hunsucker, J.L., Brah, S.B. and Sitton, R.W. Paper presented at the proceedings of the 8th annual meeting of the ASEM, Oct. 1987, St. Louis, MO.

11. "R&D to operations transition management," Hunsucker, J.L., Brah, S.B. and Law, J.S. Paper presented at the National Decision Science annual meeting, Nov. 1986, Honolulu, Hawaii.

12. "Transition management - A perspective," Hunsucker, J.L., Law, J.S. and Sitton, R.W. Paper presented at the proceedings of the 24th annual Southern Management Association Meeting, Nov. 1986, Atlanta, Georgia.

13. "Transition management - A structured perspective," Hunsucker, J.L., Law, J.S. and Sitton, R.W. Paper presented at the proceedings of the International Conference on Engineering Management: Theory and Application, Sept. 1986, Swansea, England.